

The effects of augmented feedback on landing mechanics of pediatric female soccer players.

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ABSTRACT

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(Under the direction of Darin Padua, PhD, ATC)

Objective: To determine the effects of augmented feedback on knee kinetics and kinematics of pediatric female soccer players during a jump-landing task. **Subjects:**

Twenty-seven healthy female soccer players (age = 10 ± 1 years, height = 141.02 ± 6.72 cm, weight = 33.55 ± 5.28 kg) from an area soccer league's Under-11 age division.

Methods: Subjects were randomly assigned to either control a (CON) or intervention (FB) group and performed a jump-landing task before and after an intervention period.

The FB group was provided with augmented feedback on aspects proper landing technique prior to each trial of the second set of jump-landing trials. Knee kinetic and kinematic data were collected for a total of six trials per subject and were analyzed using

a mix model analysis of variance. **Results:** Statistically significant differences were found for anterior tibial shear force (ATSF) ($F_{1,24}=4.321$, $p=.048$) and for vertical ground reaction force (VGRF) ($F_{1,24}=8.497$, $p=.008$). Moderate to large effect sizes were found

for knee valgus moment ($ES = 0.77$) and peak knee flexion ($ES = 0.68$). **Conclusion:**

Female pediatric soccer players are able to decrease ATSF and VGRF with one session of augmented feedback, indicating that augmented feedback may be an effective strategy in ACL injury prevention for pediatric athletes.

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CHAPTER 1

INTRODUCTION

TITLE

The effects of augmented feedback on landing mechanics of pediatric female soccer players.

INTRODUCTION

In the United States it is estimated that greater than thirteen million people over age seven participate in soccer (U.S. Census Bureau 2007). There are approximately 200,000 ACL injuries that occur in the United States annually, and the estimated cost of ACL reconstruction is \$17,000, which varies with differences in type of graft and hospital charges (Bonsell 2000; Griffin et al. 2000; Marshall et al. 2006). In calculating cost it is also important to consider the financial impact of rehabilitation, bracing, and treatment of long term complications that may arise (Moksnes et al. 2007). Shea et al (2004) reviewed insurance data of pediatric soccer injuries in athletes between the ages of 5-18 which indicated that 22% of adolescent soccer injuries are knee related, and ACL injuries accounted for 31% of these knee injuries. Reports by the National Collegiate Athletic Association Injury Surveillance System show that female athletes injure their ACL in approximately 3 out of every 1000 athletic exposures, which is slightly over 2.5 times more than men at the same level of competition (Prodromos et al. 2007). There is, therefore, a need to prevent ACL injuries in female soccer players beginning at the pediatric level.

Current literature examining risk factors for ACL injuries at the pediatric level is limited, and there is even less available on prevention strategies for pediatric athletes (Mandelbaum et al. 2005; Moksnes et al. 2007; Myer et al. 2007). The majority of the literature available on ACL risk factors focuses on high school athletes, however there are minimal resources that study pediatric risk factors (Arendt et al. 1999; Bonci 1999; Myer et al. 2004; Hewett et al. 2005; Hewett et al. 2007). Studies suggest that landing biomechanics are important factors when determining ACL injury risk. It is important to begin looking at the pediatric population to determine when these biomechanical factors become prominent, as well as determining an age at which it is appropriate to begin implementing prevention strategies. Studies that analyzed the landing characteristics and muscle strength development in young athletes determined that subjects had increased peak knee extension torque, increased vertical forces, and a distinct valgus knee alignment in both sexes up until approximately 14 years of age (Swartz et al. 2005; Barber-Westin et al. 2006). This information is important to note, as these factors are considered to be contributed to increased risk of ACL injury.

Prevention strategies often include strengthening, stretching, proprioceptive training, and/or plyometric exercises to address neuromuscular risk factors. While these strategies may be useful in addressing inherent deficits and imbalances, they are time consuming and require high levels of compliance, and may be difficult to apply to young athletes. Augmented feedback techniques that include verbal and visual feedback can address the primary factors that increase anterior tibial shear forces with simple verbal commands that may be combined with the visual stimulus of an expert model performing a jump landing technique (Cowling et al. 2003; Onate et al. 2005).

Using augmented feedback as a component of an ACL injury prevention program may be a key component when initiating a program for youth soccer players. It has been shown in adults that simple instructions, such as “land softer” or “bend your knees”, significantly increase knee flexion angle and decrease the magnitudes of ground reaction forces while landing (McNair et al. 2000; Cowling et al. 2003). Additionally Onate et al found in adults that visual feedback in the form of an expert model performing the same landing task as the subjects also decreased peak vertical ground reaction forces and increased maximum knee flexion angle (Onate et al. 2005). Each of these methods is easily applicable in the clinical and on-field settings, and could be appropriate methods of early ACL injury prevention by altering the mechanics of youth soccer players, which may carry over into future athletic endeavors after the onset of puberty. However, while augmented feedback has been shown to be effective in altering landing biomechanics in adults, research has not investigated the effectiveness of augmented feedback on biomechanics in a pediatric age group of subjects.

When provided with augmented feedback given after each task that includes verbal and visual cues, the pediatric population is better able to reproduce and retain information regarding their motor skills when compared to a group that received reduced feedback (Janelle et al. 2003; Sullivan et al. 2008). Studies show that pediatrics are able to acquire skills in a similar manner to adults when given verbal and visual feedback after every trial that focus on body movement, that they otherwise are unable to perform as effectively in the absence of feedback. Pediatrics given 100% feedback are also able to retain the information more than those given reduced feedback over time, which has been shown to be the most effective way to provide feedback for adults (Sullivan et al. 2008).

For this study, we will be focusing on risk factors that have been determined to have the most significant effects on ACL injury. It has been shown that increased anterior tibial shear force at the proximal end of the tibia is the primary factor that places stress on the ACL. Studies have consistently shown that decreased knee flexion angle and increased ground reaction forces, which are additionally loaded by valgus moments at the knee, are the key components to increasing anterior tibial shear forces (Arms et al. 1984; Hewett et al. 2005). In addition, as an attempt to control posterior ground reaction forces, the quadriceps contract, placing the knee in a more extended position, and thus increasing vertical ground reaction forces (Sell et al. 2007). As a result of decreased knee flexion during landing, the hamstrings do not aid in the function of the ACL by pulling the tibia posteriorly (Hass et al. 2005). The jump landing task has been utilized in these studies as well as throughout the literature to determine the presence of the risk factors noted above.

Therefore, the purpose of this study was to determine if female pediatric soccer players could alter their landing mechanics, specifically vertical and posterior ground reaction forces, knee flexion angle, anterior tibial shear force, and knee valgus, after one session of augmented feedback.

DEPENDENT VARIABLES

Kinetic and kinematic dependent variables were measured during the stance phase of a jump landing task, and the variables measured were:

1. Peak Vertical Ground Reaction Force
2. Peak Anterior Tibial Shear Force
3. Knee Flexion Angle at Initial Contact and Maximum Knee Flexion Angle

4. Peak Knee Extension Moment
5. Knee Valgus at Initial Contact and Maximum Knee Valgus
6. Peak Knee Valgus Moment

INDEPENDENT VARIABLES

Group

1. Augmented Feedback
2. No Augmented Feedback

Time

1. Pre-test
2. Post-test

RESEARCH QUESTIONS

1. Does one session of augmented feedback given to pediatric soccer players after performing a jump landing task alter the following variables?
 - a. Peak Vertical Ground Reaction Force
 - b. Peak Anterior Tibial Shear Force
 - c. Knee Flexion Angle at Initial Contact
 - d. Peak Knee Flexion Angle
 - e. Peak Knee Extension Moment
 - f. Knee Valgus at Initial Contact
 - g. Peak Knee Valgus Angle
 - h. Peak Knee Valgus Moment

2. Does augmented feedback have a greater effect on landing mechanics than practice alone in subjects that do not receive feedback?

NULL HYPOTHESES

1. H_0 : One session of augmented feedback given to pediatric soccer players after performing a jump landing task will not alter landing mechanics.
 - a. There will be no difference in peak vertical ground reaction force
 - b. There will be no difference in peak anterior tibial shear force
 - c. There will be no difference in knee flexion angle at initial contact
 - d. There will be no difference in peak knee flexion angle
 - e. There will be no difference in peak knee extension moment
 - f. There will be no difference in knee valgus at initial contact
 - g. There will be no difference in peak knee valgus angle
 - h. There will be no difference in peak knee valgus moment
2. H_0 : There will be no difference in landing mechanics between those that receive augmented feedback and those that receive no augmented feedback.

RESEARCH HYPOTHESES

1. One session of augmented feedback given to pediatric soccer players after performing a jump landing task will have an effect on landing mechanics.
 - a. Augmented feedback will result in decreased peak vertical ground reaction force.
 - b. Augmented feedback will result in decreased peak anterior tibial shear force.

- c. Augmented feedback will result in increased knee flexion angle at initial contact.
 - d. Augmented feedback will result in increased maximum knee flexion angle.
 - e. Augmented feedback will result in decreased peak knee extension moment.
 - f. Augmented feedback will result in decreased knee valgus at initial contact.
 - g. Augmented feedback will result in decreased maximum knee valgus angle.
 - h. Augmented feedback will result in decreased peak knee valgus moment.
2. Those who received augmented feedback will have greater changes in their landing mechanics than those who receive no augmented feedback.

OPERATIONAL DEFINITIONS

Pediatric: For this study pediatric was defined as between ten and eleven years of age.

Jump Landing Task: Subjects jumped off of a 30 cm box from a horizontal distance equal to 50% of the subjects' height from the edge of the force plate. The subjects then landed on both feet with their dominant foot landing on the force plate. After landing subjects were instructed to recoil and perform a rebound jump for maximal vertical height.

Dominant Leg: The leg used to kick a ball for maximum distance.

Initial Contact: When vertical ground reaction force exceeds 10N.

Toe Off: When vertical ground reaction force drops below 10N.

Stance Phase: The time period between initial contact and toe off.

Deceleration Phase: The time period between initial contact and when maximum knee flexion is achieved.

Augmented Feedback: Verbal cues given to the subject after completion of the initial measurement and before the initiation of the final measurement. The cues were scripted as, “Next time land with your knees bent, and land softly so that you can barely hear your feet hit the floor. Also do not let your knees go forward past your toes, and try to keep your knees in a straight line over your feet not in or out.” The researcher also incorporated motions that emphasized the key points within the script, such as increased knee flexion and proper knee alignment with the knee directly over the toes.

ASSUMPTIONS

1. All subjects are prepubescent.
2. All subjects were truthful about current injury status.
3. The jump landing task is a common task that increases the load on the tibia, thus increasing anterior tibial shear force.
4. Increased anterior tibial shear force, vertical ground reaction force, knee flexion angle, and knee valgus angle are accurate predictors of ACL injury risk.
5. All subjects are at the same “developmental age” from a cognitive perspective.
6. The kinematic and kinetic data collected through Motion Monitor software were reliable and valid.

DELIMITATIONS

1. All subjects are nine to eleven years old.
2. All subjects are healthy.

3. All subjects participated in soccer activity at least 1 hour per day for three days per week.
4. All analyses were performed on the dominant leg.

LIMITATIONS

1. Taking measurements of nine to eleven year old soccer players may prove difficult in generalizing results to soccer players of other ages.
2. Results cannot be generalized to include males or non-soccer athletes.

CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

The purpose of this review is to analyze the current literature on anterior cruciate ligament (ACL) injuries focusing on the pediatric population, and to provide supporting information to establish the need for research in the area of pediatric ACL injury prevention. Additional evidence will be examined to support the methods that will be used to conduct this research, and detailed explanations of concepts and theories will construct a framework for the study. This literature review will serve as a basis for which to draw from and to substantiate the rationale for the research goals, which are to determine the influence of augmented feedback on biomechanical ACL injury risk factors in pediatric athletes, and to draw conclusions about the effects of augmented feedback on landing mechanics of pediatric soccer players.

EPIDEMIOLOGY

Soccer is the most popular sport in the world with approximately 200,000 playing professionally and 240 million amateur players (2004). Over the past two decades, the number of females that participate in athletics in the United States has dramatically increased (Anderson et al. 2001), and there are higher levels of competition at younger ages,

both of which have led to an increased awareness in the sports medicine population, and increased diagnosis of ACL injuries (Fehnel and Johnson 2000).

There are approximately 200,000 ACL injuries that occur in the United States annually (Marshall et al. 2006). The estimated cost of ACL reconstruction is \$17,000 and varies based on type of graft and hospital charges (Bonsell 2000; Griffin et al. 2000). In calculating cost, it is also important to consider the financial impact of rehabilitation, bracing, and treatment of long term complications that may arise, such as osteoarthritis, physeal damage and increased instability (Moksnes et al. 2007). ACL reconstruction is not only a financial drain, but it also consumes the time of orthopedic surgeons, general medical physicians, physical therapists, athletic trainers, coaches, and families of those that incur the injury.

The current injury rates for soccer as provided by the National Collegiate Athletic Association Injury Surveillance System show that female athletes injure their ACLs in approximately 3 out of every 1000 athletic exposures, and Marshall et al. (2006) found that females have an injury rate that is 1.5 to 4.6 times higher than males. Other studies have reported that females have an ACL injury rate up to 8 times that of their male counterparts (Arendt et al. 1999; Anderson et al. 2001; Mihata et al. 2006). In order to determine why females are at an increased risk for ACL injuries, it is important to examine prepubescent and postpubescent anatomy of the lower extremity and biomechanics that are inherent in females, and if the onset of puberty and skeletal maturity increases the risk of ACL injuries. Information gathered from the pediatric population may lead to the ability to make positive biomechanical changes early within an athletic career, and may also prevent negative changes that occur post puberty.

Shea et al. (2004) reviewed insurance data of pediatric soccer injuries in athletes between the ages of 5-18 which indicated that 22% of adolescent soccer injuries are knee related, and ACL injuries accounted for 31% of these knee injuries. In the pediatric population, the effects of puberty have yet to be seen, and differences in gender are minimalized. By removing some of the confounding variables that arise during puberty as anatomical, hormonal, and biomechanical changes occur, it may be easier to tease out the true etiology of ACL injuries through biomechanical analysis, and to better address identified risk factors by intervening early on with preventative neuromuscular programs.

ANATOMY

The knee joint is comprised of three bones: the tibia, femur, and patella. Surrounding these bones are stabilizing structures that can be divided into dynamic and static categories. Dynamic stabilizers are tissues that have elastic properties and can deform with stretching and then resume regular form when tension is released. The dynamic stabilizers in the human body are muscles and tendons. There are several muscle groups that cross the knee joint that have a direct effect on the load experienced by the ACL. The two primary groups are the hamstring and quadriceps groups. The hamstrings act to flex the knee and to pull the tibia posteriorly, while the quadriceps act to extend the knee and pull the tibia anteriorly. As the strength ratio between the quadriceps and hamstrings approaches one the knee becomes more stable. This is in essence dynamic stability, and allows for the tibia to remain in a neutral position when the quadriceps and hamstrings are firing at the same time (Ford et al. 2008). During functional motions the forces created by quadriceps muscles load the ACL and the forces created by the hamstrings serve to unload the ACL (Senter and Hame 2006). For

an ACL injury to occur the muscular forces that counteract the forces that load the ACL must be overcome (Senter and Hame 2006).

Static stabilizers do not have properties that allow them to deform like dynamic stabilizers. If too much energy is transferred to static stabilizers they tear or rupture in response to the stress (Bahr and Krosshaug 2005). In the knee the static stabilizers are the lateral collateral ligament (LCL), medial collateral ligament (MCL), posterior cruciate ligament (PCL), ACL, meniscus and the joint capsule. Each ligament serves to resist a particular force that acts upon the knee. The LCL and MCL resist varus and valgus forces respectively. In an open kinetic chain the PCL resists posterior translation of the tibia on the femur and the ACL resists anterior translation of the tibia on the femur (Starkey 2002). It is important to take note that when an athlete is in a closed kinetic chain movement the ACL functions conversely to that of the open kinetic chain in that it acts more on the femur than the tibia. The function of the ACL then becomes to prevent posterior translation of the femur on the tibia.

ACL INJURY ETIOLOGY

The ACL can be loaded to the point of failure in several different ways, which can be broken up into contact and non-contact mechanisms of injury. Contact ACL injuries are rare in soccer and result from a direct blow to the posterior aspect of the tibia or the anterior aspect of the femur while the foot is planted on the ground. Either of these forces will result in loading of the ACL by placing the tibia anteriorly to the femur. Boden (2000) found that approximately 70% of all ACL injuries are non-contact in nature. Non-contact ACL injuries can occur from different types of loading mechanisms. Sagittal plane biomechanics appear

to have the greatest effect on ACL loading, and include factors such as small knee flexion angle, great posterior ground reaction force, and great quadriceps muscle forces (Yu and Garrett 2007). The ACL has also been shown to be the major structure of bearing during knee valgus/varus moments, and prevents hyperextension of the knee (Markolf et al. 1995; Fehnel and Johnson 2000). Mechanism of injury to the ACL may be due to a combined effect of many forces during an athletic maneuver, such as quick deceleration followed by a plant and pivot action. Ireland terms this point at which the ACL is overloaded to the point of failure the “position of no return”, and is described as trunk flexion and rotation to the opposite side, hip adduction and internal rotation, knee extension and valgus, tibial external rotation, and center of pressure over the ball of the foot (Ireland 1999). It is well documented that the risk factors described in the “position of no return” are more pronounced in females, and may be due to anatomical differences in the knee as well as throughout the lower extremity kinetic chain (Ireland 1999; Fehnel and Johnson 2000; Soderman et al. 2002; Hewett et al. 2005).

A study by Yu et al. (2005) found that female soccer players exhibit risk factors for ACL injury that differ from their male counterparts at age 12. This may be due to the onset of puberty, which can cause a widening at the pelvis and can place the knee in an inherent position of valgus, and over time neuromuscular control at the hips may decrease. This increases the risk of landing with knee valgus and overloading the ACL. In females, puberty causes increased hormone release which begins to alter ligamentous laxity, and therefore increases instability of the joints (Ireland 1999). There are also some anatomic differences that are evident when comparing the knees of athletes that are skeletally immature to those who are post-pubescent and have bones that are matured. The primary difference is that in

the skeletally immature knee there is the presence of an active physis located in the distal femur and proximal tibia from which primary longitudinal bone growth is occurring (Fehnel and Johnson 2000). While this does not increase the load applied to the ACL, it does increase the risk of growth abnormalities if a pre-pubescent athlete sustains an ACL injury and requires reconstructive surgery (Kocher et al. 2005). Understanding the anatomy of the knee and the ways in which the ACL is loaded, and therefore, the mechanism of injury, is important when developing prevention programs that take a multifactorial approach to addressing the risk factors associated with ACL injury.

RISK FACTORS

Research in the area of identifying risk factors for ACL injuries continues to grow, however, determining which risk factors are of greatest importance to address remains to be confirmed. There are many categories of potential ACL injury risk factors, most of which can be grouped into three types: intrinsic, extrinsic, and a combination thereof (Arendt et al. 1999; Ireland 1999). Extrinsic factors are systemic or environmental, and can be controlled once identified. Intrinsic factors are those that are anatomic, hormonal, and inherited, and cannot be controlled. Risk factors that are biomechanical have intrinsic qualities and can be partially controlled once identified, but require hard work and compliance with recommended training.

Intrinsic risk factors include anatomic knee and hip angles, ligament laxity, femoral notch size, and hormone levels. Although intrinsic risk factors are easily identifiable, several of them such as joint angles, hormone levels, and strength are not modifiable. It is only possible to address the associated neuromuscular issues that may accompany the anatomical

deviations that cause the intrinsic risk factors. It is theorized that the female anatomy lends itself to increased risk of ACL tear. In general post-pubescent females have increased femoral anteversion, increased Q angle, excessive tibial torsion, and excessive foot pronation (Bonci 1999; Griffin et al. 2000). Ligament laxity and musculotendinous flexibility are more prevalent in females, and hypermobility of the joints tends to be an inherited trait, which leads to increased motion in the female knee, making it more susceptible to forces that act on the knee (Griffin et al. 2000). Notch measurement techniques are limited, however, research shows that smaller notch width may be a risk factor for ACL injuries (Griffin et al. 2000; Anderson et al. 2001). Hormonal influences in females have been shown to have an effect on the tensile strength of the ACL during the ovulatory phase when there is a surge of estrogen (Wojtys et al. 1998; Griffin et al. 2000; Adachi et al. 2007).

Appropriate muscle strength and balance can counteract the forces that cause injury to the ACL. Muscle weakness and imbalances can be the cause of injury to the ACL. The hamstring to quadriceps ratio has been found to be higher in women than in men indicating that the females' hamstring muscles were weak relative to their quadriceps, however immature boys and girls have similar strength ratios (Bonci 1999; Anderson et al. 2001; Ahmad et al. 2006). It has been suggested that hamstring activation may protect the ACL by reducing quadriceps induced anterior tibial translation, and closed kinetic chain hamstring exercises have been shown to be successful when implemented into an ACL injury prevention program (Hewett et al. 1999; Hewett et al. 2007). An ACL injury prevention program that focuses on hamstring strengthening that is implemented into the training programs of immature athletes may maintain strength ratios and counteract the effects of maturity on those ratios in females.

Extrinsic risk factors include equipment, shoe-surface interactions, lower extremity strength, and to some extent motivation (Ireland 1999; Griffin et al. 2000). In soccer, the friction between the grass and the athlete is increased by wearing cleats. The function of the cleat is to provide increased grip on the ground so that sudden movements may be achieved without slipping, therefore increasing athletic performance. Unfortunately this causes increased tibial torsion and therefore increased risk of injury to the ACL (Griffin et al. 2000).

Biomechanical risk factors are intrinsic in nature include proprioception, neuromuscular activation patterns, and motor unit recruitment (Ireland 1999; Anderson et al. 2001). All of the previously stated factors are contributors to dynamic joint stability. The information that is transmitted to the central nervous system via afferent receptors from the muscles and tendons crossing the knee joint provides information on joint position sense. Over time the nerve pathways that are stimulated during functional sport specific movements develop into an ingrained motor pattern and allow for predetermined motions to occur by contracting specific muscles to counteract external forces that place loads on the ACL (Griffin et al. 2000). Muscle recruitment order can be developed through training programs focused on sports specific functional movements. Exercises that focus on neuromuscular control through the use of sports specific motions force the static and dynamic joint stabilizers into reflexively reacting to external stimuli in a pre-programmed manner, and protect the joint (Mandelbaum et al. 2005). Addressing biomechanical risk factors appears to have the most significant impact on ACL prevention, and although they seem to be the most complicated, they are able to be altered through simple neuromuscular preventative programs that can easily fit into a practice.

In order to address the biomechanical risk factors they must first be identified. There are several methods through which neuromuscular deficits can be determined, one of which is a jump landing task. Hewett et al. (2006) found that the use of a jump landing task during a pre-participation physical exam in order to identify risk factors such as landing forces, knee angles, and moments around the knee. A landing analysis should include observation of knee flexion angle, knee valgus angle, and kinetic forces, and from that information an assessment can be made to determine an appropriate neuromuscular training regimen.

Concurrent with study of anatomy, mechanism of injury, and biomechanical risk factors, increased anterior tibial shear force at the proximal end of the tibia is the primary factor in ACL loading. Studies have consistently shown that decreased knee flexion angle, and increased ground reaction forces, which are additionally loaded by valgus moments at the knee are the key components to increasing anterior tibial shear forces (Arms et al. 1984; Hewett et al. 2005). These risk factors are more prominent in women than in men, which has been speculated to be the reason why females have greater prevalence of ACL injuries than males (Malinzak et al. 2001; Hass et al. 2005).

Analyzing kinetic and kinematic landing strategies among male and female populations can lead to identifying risk factors and the development of ACL injury prevention programs. The question then becomes when these prevention programs should be initiated. As seen in the literature, many of the increases in risk factors begin post puberty as differences in gender begin to develop. A study by Yu et al. (2005) on age and gender effects on lower extremity kinematics concluded that the differences in kinematics between male and female youth soccer players begin around age 12, and the gap continues to widen with age.

Lower extremity motor patterns are developed over time and become a preprogrammed preparation and response strategy when performing a landing task (Chappell et al. 2007). In post-pubescent athletes, landing strategies differ significantly by gender (Chappell et al. 2002). Studies by Chapell et al. (2007) determined that females generally exhibit decreased knee flexion, hip flexion, hip abduction, and hip external rotation when compared to their male counterparts. Females also exhibited increased quadriceps activation, knee extension moment, and knee internal rotation than males when performing the same task (Chappell et al. 2002; Chappell et al. 2007). A prospective study on female athletes found that while sagittal plane motions were decreased in athletes that experienced an ACL injury, they were not as significant as coronal plane differences in injured vs. uninjured athletes (Hewett et al. 2005). The role of knee valgus angles and moments as primary predictors of ACL injury risk were discussed, and it was suggested that valgus torques on the knee can increase the anterior tibial translation and loads on the ACL exponentially. Later studies on biomechanical risk factors during landing confirmed Hewett's findings and added that high risk females also do not implement a sagittal plane loading strategy for force absorption (Myer et al. 2007). A study by Swartz et al. (2005) that compares landing kinetics between children and adults and across gender found that adults have decreased vertical ground reaction forces at initial contact when compared to children, which may be due to various levels of contribution from physical maturation, skill development, and experience.

The pediatric population exhibits a different landing strategy than that of adults, and therefore risk factors of pediatric ACL injury may also differ. Gender difference among landing strategies are rarely seen in athletes before the onset of puberty (Barber-Westin et al. 2006). Risk factors in pediatric athletes remain the same across gender and include

decreased strength, knee flexion, and hip flexion, and increased knee valgus angle and vertical ground reaction forces (Ford et al. 2005; Hass et al. 2005). Swartz et al. (2005) found that as a result of landing with decreased knee flexion and hip flexion, pediatric athletes land with greater stiffness and therefore have increased vertical ground reaction forces.

By increasing the amount of vertical forces, while maintaining knee and hip extension moments, pediatric athletes are at a great risk for ACL injury (Sell et al. 2007). At this point in growth, muscle strength and proprioception have not been fully developed (Barber-Westin et al. 2005). Participating in prevention programs that work on motor skills will decrease risk of ACL injury by addressing neuromuscular risk factors associated with decreased strength and proprioception (Hewett et al. 1999; Mandelbaum et al. 2005). In addition to physical and biomechanical risks, environmental factors play a larger role in pediatrics than in athletes who have been participating in soccer for years. Most pediatric athletes are relatively new to the game of soccer and are unfamiliar with the required equipment, and have yet to acquire the skill level needed to participate in competitive soccer, placing them at greater risk (Griffin et al. 2000).

While environmental risk factors are important to be aware of, the nature of the game of soccer is not going to adapt to the athletes, therefore other identifiable risks must be addressed. Neuromuscular risk factors are said to be identifiable in the literature beginning around age ten (Barber-Westin et al. 2005; Yu et al. 2005). It is important to recognize these risks and take steps to address them through neuromuscular training interventions. Literature also indicates that ACL injury rates in the adolescent population increases linearly after age 12 and peaks at age 17-18, and ACL reconstruction surgeries are complicated for pediatrics,

and often yield poor results (Yu et al. 2002; Arbes et al. 2007; Moksnes et al. 2007). A study done by Arbes et al. (2007) followed up with skeletally immature subjects with ACL ruptures for 5.4 years and found that 85% had radiological signs of degenerative changes. In addition, Moksnes et al. (2007) found that only 58% of children who were initially participating in activities such as soccer were able to resume their pre-injury activity level after sustaining an ACL injury. In view of the poor prognoses following treatment of ACL ruptures at a young age it is important that injury to the ACL be prevented so that athletes can maintain and progress their level of play without the pain associated with joint degeneration.

ACL INJURY PREVENTION

After identifying risk factors it becomes possible to address them with prevention strategies that may include strengthening, stretching, proprioceptive training, and/or plyometric exercises. ACL injury prevention programs usually have one of three common themes in the type of training studied. The first theme corresponds to some of the initial speculations as to the cause of ACL injuries, which are decreased strength as well as, muscle strength imbalances. Herman et al. (2008) implemented a strengthening program in an attempt to alter hip and knee biomechanics during a jump-stop task using Therabands in cardinal planes of motion, and found that all participants had significant increases in strength, however, their knee and hip biomechanics were not changed.

The next theme of preventative exercises is proprioceptive training. By building the proprioceptive mechanism allows for increased sense of position in movement so that muscular actions can be adjusted to a greater degree of accuracy (Dirckx 2001). The majority of proprioceptive training is in the form of balance activities. Soderman et al. (2000) studied

the use of a balance board in prevention of lower extremity injuries in female soccer players. The program consisted of five exercises completed on the balance board for 10-15 minutes before practice initially for 30 days in a row and then three times per week for the rest of the soccer season. The results of the study showed that there were no significant results with respect to the number, incidence, or type of traumatic injuries in the lower extremity (Soderman et al. 2000). Caraffa et al. (1996), however, found that proprioceptive training with the use of wobble boards with difficulty level progression for 20 minutes per day for three seasons decreased the amount of ACL injuries in the trained group of semiprofessional soccer players when compared to a control group.

The third prevention exercise theme is a combination of strength and dynamic stability exercises. In order to address the multiple risk factors for ACL injuries it is necessary to develop a program that incorporates flexibility, strength, neuromuscular stability, and biomechanical awareness (Caraffa et al. 1996; Myklebust et al. 2003; Mandelbaum et al. 2005; Olsen et al. 2005). Mandelbaum et al. (2005) studied female soccer players between the ages of 14 and 18 over two years and found that a sports specific intervention that included education, stretching, strengthening, plyometric exercises, and sport specific drills decreased ACL injuries an average of 81% compared to age matched counterparts in the control group. Olsen et al. (2005) addressed risk factors by incorporating strength, balance, and cutting technique exercises throughout a handball season. In addition to completing the exercises, the athletes were asked to emphasize a “knee over toe” position and to give each other feedback during the training exercises. This program resulted in a greater than 50% decrease in acute knee injuries in the intervention group when compared with the control group. Hewett et al. took a slightly different approach and focused on the

biomechanics of landing as a primary source of knee injury prevention in females. The intervention was incorporated 3 days per week and began with warm up and stretching, followed by jump training program included phases that focused on technique, fundamentals, and performance, and concluded with a fully body weight training program. They found that the incidence of serious knee injury was 2.4 to 3.6 times higher in the untrained group than in the trained group (Hewett et al. 1999). These studies show that by addressing multiple risk factors through intervention strategies, it is possible to reduce the incidence of ACL injuries.

The amount of risk factors that contribute to ACL injury can appear to be overwhelming when attempting to develop prevention strategies. By breaking the risk factors into groups that may be addressed by similar intervention exercises the task becomes less daunting. It has been shown that although females have some anatomic risk factors that create a higher risk for ACL injury, neuromuscular training as an intervention can address the biomechanical risk factors, thus overriding a number of the anatomical and extrinsic risk factors (Hewett et al. 1999; Myklebust et al. 2003; Mandelbaum et al. 2005; Olsen et al. 2005). Landing tasks are often used to measure biomechanical risks that are linked to ACL injuries (Fagenbaum and Darling 2003; Onate et al. 2005; Barber-Westin et al. 2006; Chappell et al. 2007; Sell et al. 2007). It seems only appropriate to address these biomechanical risk factors through neuromuscular training that focuses on landing strategies, and exercises to modify those risk factors.

It is necessary to address strength deficits and imbalances that cause segments to move in ways that increase risk of ACL injury. Concentric strengthening the anterior and lateral hip musculature addresses deficits in hip flexion and excessive knee valgus by placing the femur in a more flexed and abducted position during landing. Eccentric strengthening of

the posterior hip assists the hamstrings in providing stability in a deep hip flexed position because in that position the hamstrings are stabilizing the trunk by contracting while in a lengthened position, and therefore keep the body in an upright position. Concentric hamstring strengthening assists in knee flexion, and provides a posterior force to the tibia, which assists the ACL in its function. A core strengthening program is also essential to enhancing functional motions in the extremities.

Focusing on motor skills allows an intervention to become more functional and sport specific for athletes. As discussed previously, neuromuscular motor patterns built through repetition of tasks that emphasize proper technique and incorporate proprioception may be the key to minimizing the majority of biomechanical risk factors (Hewett et al. 1999; Lephart et al. 2005). Exercises in landing and cutting techniques that focus on hip, knee, and foot position and alignment have been shown to decrease landing forces that directly translate to forces in the joints of the lower extremity (Hewett et al. 1999). Neuromuscular training interventions require the nervous and musculoskeletal systems to work together in order to create joint stability during functional tasks and decrease the risk of ACL injury. Limitations in the studies on neuromuscular training interventions included the possibility that the time period allotted for the training program was not enough time for subjects to fully benefit from the program, and that subjects may have not fully complied with the prescribed program as most were performed outside of the lab (Lephart et al. 2005; Mandelbaum et al. 2005; Olsen et al. 2005). Due to these limitations it is important to create a neuromuscular training program that is easy to comply to so that long term effects can be assessed.

AUGMENTED FEEDBACK

As the number of females who participate in soccer increases, the need for a prevention program also increases. Although the prevention programs discussed above have been successful in reducing the incidence of ACL injuries, they require a large amount of time and compliance from the athletes. In pediatric populations preventative strategies that require lengthy attention spans and focused participation may not be easily applicable, and therefore may not serve their purpose. A more appropriate approach for pediatric athletes would address biomechanical risk factors efficiently, focusing on the ease of completion with proper technique. Verbal and visual augmented feedback in reference to correcting landing strategies takes a minimal amount of time, is clinically applicable, and allows the athletes to take the intervention into their own hands by educating them on proper techniques.

The effects of simple instruction on landing strategies have been shown to successfully decrease landing forces and increase muscle activation required for dynamic stability (Prapavessis and McNair 1999; McNair et al. 2000; Cowling et al. 2003; Prapavessis et al. 2003). Verbal augmented feedback can be changed to provide instruction differently in order to address the different aspects of landing strategies. For example, feedback that focuses on kinematic technique or environmental cues has been effective in decreasing vertical ground reaction forces during landing. In a study performed by Cowling et al. the instructions given were to “land with the knee bending and to turn the muscles in the back of the thigh on earlier and more before landing”. Vertical ground reaction forces were significantly decreased when subjects were told to land with the knee bending, however the group that was instructed on hamstring activation showed significantly increased vertical ground reaction forces (Cowling et al. 2003). This substantiates the effects of simple verbal

instruction on changing knee flexion angle during landing, which results in decreasing vertical ground reaction forces. It also shows that increasing the complexity of the instruction may prove to be difficult for subjects to understand, even at age 21. Hence, for the pediatric population, simple instructions will be more easily comprehended and have a greater likelihood of being executed correctly. McNair et al. (2000) studied the effects of instruction and of environmental cues on landing forces and found that technical instructions related to kinematics led to significant decreases in peak vertical ground reaction forces, and that instructions focused on the sound of the feet hitting the ground also had a significant effect on decreasing vertical ground reaction forces, both of which improved landing performance.

Visual feedback can also address biomechanical risk factors associated with ACL injury by stimulating visual sensory-feedback mechanisms, through which supplemental information is provided above and beyond the inherent information that is naturally available to the individual (Onate et al. 2005). By observing the correct way to perform a landing task athletes see correct body alignment, hear how the feet landing on the ground should sound, and has a basis for comparing their own landing strategies. A study by Onate et al. (2005) compared the effects of videotape feedback, one type was of an expert model performing the landing task correctly, and the second type was a video of the actual subject performing the task, and the third type was a combination of the previous two types. The main finding of the study was that the subjects that trained with the videotape augmented feedback had significantly decreased peak vertical ground reaction forces and increased maximum knee flexion angles. The post hoc results determined that the videotape feedback that included observing the initial trials of the subject performing the jump landing task were more

effective than only viewing the expert model. It was theorized that learning is a problem-solving process and the more involved the subject is in analyzing his or her own performance, the greater the learning value is (Onate et al. 2005). While this type of feedback is best in the research setting it is not always clinically applicable. It may be more feasible for an “expert” who knows proper landing technique to perform the landing task in front of the athletes to provide immediate feedback, and not have to wait for videotape to process and be edited.

There is a minimal amount of literature on motor learning in the pediatric population, however it is known that children have different information-processing abilities than adults, such as selective attention and speed of information processing (Sullivan et al. 2008). In a study done by Sullivan et al. (2008) it was found that children who receive feedback after every trial of an elbow flexion/extension task had greater retention than children who received feedback 62% of the time, and in fact performed comparably to adults at the end of acquisition and retention trials. In addition, a study by Hamstra et al. (2006) found that children who participated in sports displayed more refined motor programs used to execute high-velocity tasks, which suggests a difference in feedforward motor programming. This suggests that with practice, pediatrics are able to alter their motor patterns to become more efficient. It is important to note that there is a point in which practice benefits for learning are maximized, and if the level of challenge exceeds that point, then the resulting cognitive effort may be beyond the capabilities of the learner, hindering learning benefits (Sullivan et al. 2008).

A combination of verbal and visual augmented feedback may be the best way for pediatric athletes to comprehend and execute biomechanical intervention strategies in an on-

field setting. By stimulating multiple senses it will be easier to maintain the attention of athletes performing the intervention and to ensure proper form, and verbal instruction will provide feedback and confirmation of proper technique.

PEDIATRICS

Literature on ACL injury prevention in pediatric athletes is limited. Pediatric athletes may have a higher risk of injuring their ACL than their adult counterparts due to lack of skill, experience, and environmental and biomechanical risk factors (Bonci 1999; Ireland 1999; Griffin et al. 2000; Anderson et al. 2001). Currently most injury prevention programs focus on high school and college athletes, however more significant changes in motor skill may be made by beginning interventions in pediatrics by teaching appropriate motor patterns earlier and allotting more time to practice and apply these methods. Pediatrics athletes are not just smaller adults, and have many anatomic orthopedic differences from those who are skeletally mature. This becomes an issue when a pediatric athlete experiences an ACL tear. While many collegiate athletes receive operative reconstruction of the ACL, the current standard of treatment for pediatric athletes is much more conservative. This is due to the presences of open epiphyseal plates in the femur and tibia, which for a traditional reconstruction are drilled into so that a graft may be inserted in place of the torn ACL. Performing a traditional ACL reconstruction on an athlete with open epiphyseal plates can lead to iatrogenic growth disturbances due to physeal arrest (Kocher et al. 2005). A survey given to the Herodicus Society and the ACL Study Group revealed that the majority of surgeons opt for initial non-operative management in 8-13 year old patients with complete acute ACL disruption (Kocher et al. 2005). When ACL reconstructive surgery is performed on a pediatric athlete it may

lead to higher instability rates, increased knee joint laxity, and early onset of osteoarthritis, and additional surgery may be required when the patient reaches skeletal maturity (Edwards and Grana 2001; Utukuri et al. 2006; Arbes et al. 2007; Moksnes et al. 2007).

In a study done on the functional outcome for children 12 years or younger following ACL injury it was determined that athletes who participate regularly in pivoting sports, such as soccer, return to their previous activity level only 58% of the time when treated non-operatively (Moksnes et al. 2007). The need for injury prevention strategies for pediatric athletes that participate in soccer is apparent due to the high incidence of ACL injuries in soccer and the poor outcomes that occur with ACL tears in the pediatric population.

As augmented feedback has been shown to be effective in altering the biomechanics of adults, it may also be effective in altering the biomechanics of pediatrics. Through 100% augmented feedback including verbal and visual cues the pediatric population is better able to reproduce and retain information regarding their motor skills (Janelle et al. 2003; Sullivan et al. 2008). Studies show that pediatrics are able to acquire skills in a similar manner to adults when given verbal and visual feedback after every trial that focus on body movement. Pediatrics are also able to retain the information to a greater extent than those given reduced feedback over time, which has been shown to be the most effective way to provide feedback for adults (Sullivan et al. 2008).

CONCLUSION

ACL injury prevention programs that begin at the pediatric level may have the ability to not only prevent pediatric ACL injuries, but may also provide athletes with the basic motor skills needed to prevent future ACL injuries. ACL injuries can result in great financial and

emotional costs, as well as, having a poor functional outcome over time. There is a need for more research in the area of pediatric ACL injury prevention to determine the best methods of screening and preventative strategies to implement for young athletes. In the pediatric population injury prevention may begin with basic feedback to correct biomechanical risk factors. Early recognition of risk factors followed by early intervention to address those risk factors leads to a decrease in the prevalence of ACL injuries.

CHAPTER 3

METHODOLOGY

SUBJECTS

Twenty seven female subjects were recruited from an area soccer league's Under-11 age division (age = 10 ± 1 years, height = 141.02 ± 6.72 cm, weight = 33.55 ± 5.28 kg). Subjects were randomly assigned to groups by choosing a number without replacement. Group one (CON) was the control group, and did not receive any feedback. Group two (FB) was the intervention group, and was provided with feedback. Each of the groups contained 13 subjects and the observed power analysis for the study is depicted in Table 1.

Inclusion / Exclusion Criteria

Subjects were eligible for the study if they were on the official roster for the Under-11 or Under-10 age divisions, and engaged in soccer activity for 1 hour at least 3 days per week. Any of the subjects who had an injury that prohibited them from soccer participation at the time of testing were excluded. Subjects were also excluded if they had a history of lower extremity injury that required surgical intervention within the past year, or were completing a formal rehabilitation program at a physical therapy clinic at the time of testing, as this may have affected lower extremity biomechanics and skewed the data.

MEASUREMENT & INSTRUMENTATION

All measurements were conducted on the dominant leg of each subject, which was defined as the leg used to kick a ball for maximal distance, which is consistent with current literature (Hanson et al. 2008). An infrared optical motion capture system (Vicon Motion Systems, Centennial, CO) consisting of 7 infrared cameras was used to sample knee kinematics during the task by capturing the movement of reflective markers attached to each subject at a frequency of 120 Hz. Landing forces were sampled from a conductive force plate (Bertec Corporation, Columbus, OH) at a frequency of 1,200 Hz, and those data were combined with knee kinematics via an inverse dynamics procedure to derive knee kinetics. All data were collected using Vicon Nexus Software (Vicon Motion Systems, Centennial, CO).

PROCEDURES

Subjects reported to the Sports Medicine Research Laboratory at the University of North Carolina at Chapel Hill for a single testing session lasting approximately one hour. Informed consent and assent forms approved by the Institutional Review Board were completed prior to the testing date. Upon arriving at the laboratory, the subjects completed a questionnaire to screen for current injuries that prohibited them from playing soccer, and their height and weight were recorded. The subjects were then randomly assigned to groups by choosing a number without replacement. The Vicon and force plates were calibrated before each testing session.

Subjects wore spandex shorts and a shirt, and their own sneakers for the testing session. Retroreflective markers were placed on the subjects bilaterally on the acromion

processes, greater trochanters, anterior superior iliac spines, anterior thighs, lateral femoral condyles, medial femoral condyles medial malleoli, tibias, lateral malleoli, and on the sacrum. Markers were also placed on the subjects' shoes, representing the head of the 1st metatarsal, head of the 5th metatarsal, and calcaneus.

Following marker placement, the subjects were asked to stand in the center of the calibration area (2.5 m high \times 2.5 m long \times 1.5 m wide) with each foot on a Bertec forceplate (Type 4060-08, Bertec Corporation, Worthington, OH), in order to collect a static calibration trial. Following the static calibration trial the retroreflective markers on the medial malleoli and medial epicondyles were removed for ease of movement during data collection of the jump landing task.

Both groups performed the same jump landing task from a 30 cm box that was placed at 50% of the subjects' height from the front edge of the force plate. The jump landing task has been used consistently to obtain information on kinetics and kinematics at the knee in order to determine potential risk factors for ACL injuries (Fagenbaum and Darling 2003; Pflum et al. 2004; Barber-Westin et al. 2005; Hass et al. 2005; Hewett et al. 2005; Myer et al. 2007). Subjects were instructed to jump forward and land with their dominant foot on the forceplate being analyzed, and then immediately jump up for maximum vertical height upon landing, and then land back on the force plates. If the task was not performed correctly subjects were asked to redo the trial. A bad trial was defined as subjects not landing with their entire dominant foot on the force plate, jumping vertically instead of jumping horizontally toward the force plate, or if the non-dominant foot landed on the force plate being analyzed.

Subjects performed the jump landing task as described above before and after an intervention period. A jump landing task was defined as a set of 3 jump landing trials off of a 30cm box placed at a distance of on half of the subjects' height from the edge of the force plate. All subjects performed the first jump landing task and then followed the testing procedures specific to their assigned group.

Control Group

One minute of rest was given between jump landing tasks. During the second set of jump landing trials, the subjects in the CON group were given one minute of rest between each trial of the second jump landing task in order to emulate the time needed to provide feedback to the FB group.

Feedback Group

The FB group also performed the first jump landing task, and were then provided with feedback that took approximately one minute to administer. The scripted feedback consisted of: "I want you to remember three things. 1) Bend your knees when you land. 2) Land softly so you can barely hear your feet hit the floor, and 3) Land with your knees in a straight line over your toes." The subjects then performed another jump landing task, and received 100% feedback, meaning that feedback was given between each trial in accordance with the literature on motor learning in children (Janelle et al. 2003; Emanuel et al. 2008; Sullivan et al. 2008).

DATA REDUCTION

World axes were defined using the right hand rule, where x was positive in the anterior direction that the subjects were facing, y was positive to the left of each subject, and

z was positive in the superior direction. Phases of the jump landing task were defined by events within the vertical ground reaction force data. Initial ground contact was defined as the point at which the vertical ground reaction force exceeded 10N. Take-off was defined as the point after initial ground contact at which the vertical ground reaction force dropped below 10N. All data were analyzed within the time interval from initial contact until 50% of the stance phase. All peak angles, forces, and moments were measured during the stance phase.

Data reduction was performed using Motion Monitor software and a customized software program (MatLab), and was used to calculate:

1. Knee valgus at initial contact
2. Peak knee valgus angle
3. Peak knee valgus moment
4. Knee flexion angle at initial contact
5. Peak knee flexion angle
6. Peak knee extension moment
7. Peak vertical ground reaction force
8. Peak anterior tibial shear force

Force measurements were divided by the subjects' body weight, and moments were the product of height and weight in order to normalize the data.

DATA ANALYSIS

All data were analyzed using SPSS 15.0 (SPSS, Inc. Chicago, IL). An alpha level of 0.05 was set and a power analysis was run post data analysis. A 2x2 (group x time) Repeated

Measures ANOVA was conducted to answer the research questions outlined in Table 2. A Tukey post hoc analysis was conducted on data that were determined to be statistically significant, and effect sizes were calculated for all data.

CHAPTER 4

RESULTS

Three trials and one subject were not analyzed as the vertical ground reaction force data were corrupt due to large amounts of missing forceplate data within the trial, and subsequently accurate kinetics and kinematics were unable to be obtained. Subjects 226 and 232 also had large gaps missing forceplate data in vertical ground reaction forces for trial one, and subject 215 had the same problem on trial three. Subject 203 was also affected by corrupt vertical ground reaction force data in all trials, and was therefore removed completely from analysis.

Means and standard deviations for kinematics and kinetics data are presented in Tables 3 and 4, respectively. Statistical analyses revealed significant group by test interactions for anterior tibial shear force ($F_{1,24}=4.32$, $p=0.05$) and vertical ground reaction force ($F_{1,24}=8.497$, $p=0.01$). Tukey post hoc analysis of anterior tibial shear force data (MSD critical value = 0.10 N/Kg) revealed a significant difference between CON and FB groups post intervention (mean difference = 0.19 N/Kg) suggesting that the decreased anterior tibial shear force in the feedback group was due to the augmented feedback. Tukey post hoc analysis of vertical ground reaction force data (MSD critical value = 0.63 N/Kg) revealed significant differences within the feedback group from pre to post intervention (mean difference = 0.99 N/Kg) and between control and feedback groups post intervention (mean difference = 0.91 N/Kg). There were no significant differences found between the groups at

pre test, nor were there any differences observed within the control group between testing points. This suggests that augmented feedback reduced vertical ground reaction forces in the feedback group that was greater than the practice effect experienced by the control group.

Additionally, no significant group by test interactions were revealed for peak knee valgus moment ($F_{1,24}=1.63$, $p=0.21$) or knee extension moment ($F_{1,24}=0.86$, $p=0.36$). These findings suggest that the intervention did not influence either knee valgus or extension moments. However, the effect size associated with the feedback group's knee valgus moment data indicates a large effect ($ES = 0.77$) (Table 4) whereby knee valgus moment was decreased by 70% following the intervention. This indicates that while not statistically significant the intervention may have had a clinically meaningful influence on knee valgus moment.

No significant group by test interactions were observed for the kinematic variables of knee flexion at initial contact ($F_{1,24}=0.07$, $p=0.80$), peak knee flexion ($F_{1,24}=1.16$, $p=0.29$), knee valgus at initial contact ($F_{1,24}=2.77$, $p=0.11$), and peak knee valgus ($F_{1,24}=2.63$, $p=0.12$). Based on these findings we conclude that these variables were not affected by the intervention. It should be noted that a moderate to large effect size was associated with the peak knee flexion angle data for the feedback group ($ES = 0.68$) (Table 3). The feedback group increased peak knee flexion by approximately 7° following the intervention, which represents a 9% increase. As no significant differences were found in peak knee flexion or knee flexion at initial contact, we chose to analyze the difference in knee range of motion from initial contact to peak knee flexion, which also did not yield any statistically significant results ($F_{1,24}=1.06$, $p=.314$). We believe the moderate to large effect size for peak knee

flexion angle represents a clinically meaningful change in peak knee flexion following the intervention that warrants further investigation.

CHAPTER 5

DISCUSSION

The purpose of this study was to evaluate the effects of augmented feedback on the landing mechanics of female pediatric soccer players. The primary findings suggest that subjects who received augmented feedback after each trial of a jump landing task over the course of one testing session demonstrated significant decreases in anterior tibial shear force (ATSF) and vertical ground reaction force (VGRF) compared to a control group that did not receive feedback. Our findings support the hypotheses that augmented feedback would decrease anterior tibial shear force and vertical ground reaction force, however they reject the hypotheses that augmented feedback would decrease peak knee valgus, knee valgus at initial contact, knee valgus moment, peak knee extension moment, and would increase peak knee flexion and knee flexion at initial contact.

Our findings support previous research on decreasing VGRF with augmented feedback (Prapavessis and McNair 1999; McNair et al. 2000; Onate et al. 2001; Cronin et al. 2008). There were, however, a lack of statistically significant results in our kinematic variables which may indicate that the necessary compensations involved in decreasing VGRF and ATSF may be occurring at a lower extremity joint other than the knee. Current literature suggests that a decrease in ATSF is a result of a change in sagittal plane kinematics (Sell et al. 2007). We chose to examine kinetics and kinematics at the knee as they have been shown to have an association with ACL injury in adults

(Arms et al. 1984; Arendt et al. 1999; Bonci 1999; Ireland 1999; Hewett et al. 2005). In accordance with research on potential risk factors for ACL injury, the changes that we observed in VGRF and ATSF have profound clinical applications in that a decrease in these variables as a result of augmented feedback may lead to a decreased risk of ACL injury (McNair and Marshall 1994; Hewett et al. 2005).

Our findings agree with previous research which suggests that VGRF can be reduced with augmented feedback in adult populations (Onate et al. 2001). Studies on the effects of augmented feedback found that peak VGRF was significantly decreased in adults, and adolescents were also able to decrease VGRF by 19% after being given technical instruction related to joint positions and auditory cuing (Prapavessis and McNair 1999; McNair et al. 2000). Prapavessis et al. (2003) researched the ability of nine year old children to decrease VGRF through the use of augmented feedback and found that the subjects in the instruction group significantly decreased VGRF in one session when compared to a control group, however they were unable to retain the information when tested again after three months. Our study found that pediatric females were able to decrease their VGRF by approximately an entire body weight when compared to a control group that remained virtually the same. This finding suggests that pediatric female soccer players may decrease their risk of ACL injury when provided with simple instruction regarding proper landing mechanics.

A decrease in VGRF is clinically meaningful because peak ACL strain occurs at the instant of peak VGRF, indicating that a hard landing may be a risk factor for sustaining non-contact ACL injuries (Yu and Garrett 2007). Peak VGRF occurs simultaneously with peak posterior ground reaction force during stop jump tasks, which causes an external flexion moment relative to the knee. In response to this, an internal knee extension moment must

occur through forceful contraction of the quadriceps, which in turn causes an increase in proximal ATSF (Yu et al. 2006). This supports the correlation that McNair and Marshall observed between anterior tibial acceleration and VGRF during a jump landing task (McNair and Marshall 1994).

A study on the mechanism of non-contact ACL injuries revealed that ATSF is the primary component in anterior tibial translation and as a result places strain on the ACL during dynamic movements, which is the direct cause of ACL tears (Chappell et al. 2002; Yu and Garrett 2007). Many biomechanical factors have been identified as possible predictors of ACL injury as they lead to increased ATSF and subsequent loading of the ACL (Arendt et al. 1999; Ireland 1999; Chappell et al. 2002; Yu and Garrett 2007; Shimokochi and Shultz 2008). Due to the relationship that has been found in previous studies between ATSF and ACL strain, the decrease we found in ATSF with augmented feedback can be applied clinically to potentially decrease the risk of ACL injury. The few studies that have been conducted on the effects of augmented feedback as an injury prevention strategy have not analyzed ATSF as a dependent variable. This is the only study thus far that has examined the pediatric population and analyzed additional kinematic variables as well as kinetics that have been identified as possible predictors for ACL injury. In examining the combination of kinematic and kinetic variables, the use of augmented feedback shows promise in decreasing the risk of ACL injury in pediatric females that participate in high risk sports such as soccer. The majority of current literature on augmented feedback as it relates to injury prevention focuses on adult populations (Prapavessis and McNair 1999; McNair et al. 2000; Onate et al. 2001; Cronin et al. 2008). Augmented feedback provides specific supplemental information about performance to the subject that they would otherwise be unable to obtain on their own

through practice and sensory feedback (Onate et al. 2001). In pediatric populations preventative strategies that require lengthy attention spans and focused participation may not be easily applicable, and therefore may not serve as an effective injury prevention technique.

Our study is unique in that it evaluates the effects of augmented feedback on the landing mechanics of the pediatric population. It is important to take into account the motor learning abilities of children when incorporating augmented feedback into an injury prevention program. A study on skill acquisition in pediatrics found that children require longer periods of practice with a greater frequency of feedback than young adults in order to optimize motor learning (Sullivan et al. 2008). The results from this study suggest that female soccer players between the ages of nine and eleven are able to significantly decrease the amount of force sustained by their knees by providing them with simple instruction. The feedback given to the subjects in our study were concise and required a minimal amount of time, which allowed us to provide feedback after every trial (at 100% rate), and therefore the subjects were able to complete several jump landing trials while incorporating the feedback that was given to them, thus creating successful results.

Our study agrees with a that conducted by Prapavessis (2003) on the ability of children to decrease VGRF through the use of augmented feedback. It was found that the subjects in the feedback group significantly decreased VGRF in four sessions within one week when compared to a control group. In that study, however, the feedback group was not significantly different from the control group when tested at three months post initial instruction (Prapavessis et al. 2003). This indicates that pediatrics may not be able to retain the information provided in the feedback over long periods of time. As the subjects in this study were only provided with feedback during one session, trends in kinematic results may

indicate the need to incorporate multiple sessions of augmented feedback over a greater length of time, such as in part of an injury prevention program, in order to see statistically significant results. In our study we did not evaluate the ability of the subjects to retain the feedback provided, so we are currently unable to compare that aspect to the study completed by Prapavessis (2003).

Based solely on the statistically significant differences that we found in VGRF and ATSF, our study has clinical significance as we have shown that simple augmented feedback can decrease those variables in nine to eleven year old female soccer players. By using this simple technique at the pediatric level it may be possible to address biomechanical issues in female athletes before they become poor habits, and it may therefore be possible to reduce the risk of ACL injury in that population as a direct result of decreasing ATSF.

Although not all of the measured variables revealed statistically significant differences, comparisons within the feedback group suggested that there were trends from pre to post intervention that with a additional subjects may have elicited statistically significant differences. These trends were suggested by our findings of moderate to large effect sizes of peak knee flexion and knee valgus moment. The changes observed for peak knee flexion and knee valgus moment show promise clinically in decreasing the risk of ACL injury as the feedback group displayed a 70% decrease in knee valgus moment, and peak knee flexion increased by approximately 7°. This is important in decreasing risk of ACL injury as greater knee flexion and lesser knee valgus moment cause a decrease in ATSF, and in turn decrease the load sustained by the ACL (Yu and Garrett 2007).

There are many directions in which future research on this subject may lead to new discoveries regarding ACL injury prevention beginning in the pediatric population. Similar

studies may be conducted to determine the effects of augmented feedback on different age groups in the pediatric population, as well as observing if pediatric males and females respond differently to augmented feedback. Future studies may also examine the effects of multiple sessions of augmented feedback over time on kinetic and kinematic variables, which may also extend into researching multiple lower extremity joints to determine where modifications have occurred in order to cause a decrease in VGRF and ATSF. When analyzing the effects of augmented feedback on landing mechanics a study on the retention of initial feedback provided should be examined. Researchers may also find it prudent to determine if augmented feedback given over a substantial period of time actually will decrease the incidence of ACL injury in pediatrics.

We acknowledge that the current study has several limitations, one of which is the sample size. The conclusions drawn from this study can only be applicable to females between the ages of nine and eleven. In accordance with this, no analysis was completed on the subjects' psychological abilities to retain and incorporate the feedback provided. As with many laboratory studies, the jump-landing task was performed with retroreflective markers attached to the subject, and while the jump-landing task is an athletic movement, it may not be a true indication of movement on an athletic field. Also, this study cannot actually determine if decreasing any of the measured variables will actually result in a decreased risk of ACL injury as we have not followed our subjects over time.

The current study investigated the effects of augmented feedback on kinetic and kinematic variables associated with pediatric landing strategies during a jump-landing task. Based on the results of this study it can be concluded that:

1. Augmented feedback significantly decreases ATSF and VGRF in female pediatric soccer players, and may reduce the risk of ACL injury.
2. While kinematic variables did not yield statistically significant results, further investigation is needed to determine if the necessary compensations for decreasing VGRF and ATSF are coming from a joint other than the knee.
3. Moderate to large effect sizes observed in knee valgus moment and peak knee flexion warrant further investigation to determine if augmented feedback may elicit significant differences with a greater number of subjects.

APPENDIX A: TABLES

Table 1. Power Analysis

Dependent Variable	Sample Size	Observed Power
Knee Flexion at IC	26	0.34
Peak Knee Flexion	26	0.12
Knee Range Of Motion	26	0.51
Knee Valgus at IC	26	0.09
Peak Knee Valgus	26	0.05
Peak ATSF	26	0.51
Peak VGRF	26	0.80
Peak Knee Extension Moment	26	0.08
Peak Knee Valgus Moment	26	0.09

Table 2. Data Analysis

Question	Description	Dependent Variables	Comparison	Analysis
1	Does augmented feedback given at a rate of 100% alter landing kinematics when compared to a group that does not receive augmented feedback ?	Knee Flexion at IC Peak Knee Flexion Knee Valgus at IC Peak Knee Valgus Knee Extension Moment Knee Valgus Moment	Control vs. Feedback	2x2 Repeated Measures ANOVA (group x time)
2	Does augmented feedback given at a rate of 100% alter landing kinetics when compared to a group that does not receive augmented feedback ?	Peak VGRF Peak ATSF	Control vs. Feedback	2x2 Repeated Measures ANOVA (group x time)

Table 3. Knee flexion and valgus angles (degrees) at initial contact (IC) and peak over stance phase for Feedback and Control groups

Kinematics	Group	Pre-Test			Post-Test			Effect Size	Power
		Mean	SD	95% CI	Mean	SD	95% CI		
Knee Flexion IC (deg)	Control	19.9	4.16	17.1, 22.8	19.5	4.74	16.9, 22.1	0.002	0.34
	Feedback	16.9	5.7	14.0, 19.8	16.8	4.23	14.2, 19.3	0.02	
Knee Flexion Peak (deg)	Control	77.9	4.67	73.4, 82.5	81.2	11.1	74.2, 88.1	0.41	0.12
	Feedback	73.3	10.17	68.8, 77.8	80.5	13	73.6, 87.5	0.68	
Knee ROM	Control	61.7	1.04	54.4, 61.6	58.0	5.84	55.5, 67.9	1.95	0.51
	Feedback	63.8	1.13	52.8, 60.0	56.4	6.68	57.6, 70.0	-0.03	
Knee Valgus IC (deg)	Control	0.78	3.09	-0.82, 2.37	0.87	3.63	-0.94, 2.68	0.03	0.09
	Feedback	-0.28	2.44	-1.88, 1.31	0.61	2.6	-1.20, 2.42	0.04	
Knee Valgus Peak (deg)	Control	4.1	6.17	1.08, 7.12	4.03	6.88	0.48, 7.58	-0.01	0.05
	Feedback	2.92	4.2	-0.10, 5.94	4.47	5.43	.92, 8.02	0.32	

Note: Values represent mean standard deviation (95% confidence interval). Effect size was calculated by dividing the sums of the means by the larger SD.

**Indicates significant group by test interaction*

Table 4. Normalized VGRF, ATSF, Knee valgus moment and Knee extension moment over stance phase for Feedback and Control groups

Kinetics	Group	Pre-Test			Post-Test			Effect Size	Power
		Mean	SD	95% CI	Mean	SD	95% CI		
VGRF (BW)	Control	3.5	0.65	3.12, 3.86	3.19	0.709	2.85, 3.53	0.46	0.8
	Feedback *	3.27	0.63	2.91, 3.64	2.29	0.44	1.95, 2.62	1.8	
ATSF (BW)	Control	0.33	0.22	0.23, 0.42	0.39	0.22	0.29, 0.50	0.24	0.51
	Feedback *	0.24	0.1	0.14, 0.34	0.21	0.13	0.10, 0.31	0.3	
Knee Valgus Moment (BWxBH)	Control	-0.07	0.13	-0.14, -0.01	-0.07	0.12	-0.11,-0.02	0.07	0.09
	Feedback	-0.07	0.11	-0.14, -0.01	-0.02	0.03	-0.07, .03	0.77	
Knee Extension Moment (BWxBH)	Control	-0.5	0.17	-0.59, -0.40	-0.42	0.11	-0.49,-0.34	0.21	0.08
	Feedback	-0.44	0.15	-0.54, -0.35	-0.42	0.14	-0.49, -0.35	0.13	

Note: Values represent mean standard deviation (95% confidence interval). Effect size was calculated by dividing the sums of the means by the larger SD.

**Indicates significant group by test interaction*

APPENDIX B: MANUSCRIPT

INTRODUCTION

In the United States it is estimated that greater than thirteen million people over age seven participate in soccer (U.S. Census Bureau 2007). Shea et al. (2004) reviewed insurance data of pediatric soccer injuries in athletes between the ages of 5-18 which indicated that 22% of adolescent soccer injuries are knee related, and ACL injuries accounted for 31% of these knee injuries. Reports by the National Collegiate Athletic Association Injury Surveillance System show that female athletes injure their ACL in approximately 3 out of every 1000 athletic exposures, which is slightly over 2.5 times more than men at the same level of competition (Prodromos et al. 2007). An injury prevention strategy that can begin at the pediatric level may be able to decrease the amount of ACL injuries sustained by female soccer players.

Current literature examining risk factors for ACL injuries at the pediatric level is limited, and there is even less available on prevention strategies for pediatric athletes (Mandelbaum et al. 2005; Moksnes et al. 2007; Myer et al. 2007). The pediatric population exhibits a different landing strategy than that of adults in that they have decreased knee flexion, decreased hip flexion, decreased strength, increased knee valgus, and increased vertical ground reaction forces (Ford et al. 2005; Hass et al. 2005). Biomechanical risk factors are associated with dynamic joint stability and include proprioception, neuromuscular activation patterns, and motor unit recruitment (Ireland 1999; Anderson et al. 2001).

Focusing on motor skills allows an intervention to become more functional, expanding from the cardinal planes of motion and moving more towards sport specific motions for athletes. Neuromuscular motor patterns built through repetition of tasks that

emphasize proper technique and incorporate proprioception may be the key to minimizing the majority of biomechanical risk factors (Hewett et al. 1999; Lephart et al. 2005).

Exercises in landing and cutting techniques that focus on hip, knee, and foot position and alignment have been shown to decrease landing forces that directly translate to forces in the joints of the lower extremity (Hewett et al. 1999). Neuromuscular training interventions require the nervous and musculoskeletal systems to work together in order to create joint stability during functional tasks and decrease the risk of ACL injury.

It is important to begin looking at the pediatric population to determine when biomechanical risk factors become visible through evaluation, as well as determining an age at which it is appropriate to begin injury prevention programs. By addressing biomechanical deficits at the pediatric level it may be possible to prevent risk factors for ACL injury that have been identified in adolescents and adults. In the pediatric population, preventative strategies that require lengthy attention spans and focused participation may not be easily applicable, and therefore may not serve their purpose. A more appropriate approach for pediatric athletes would address biomechanical risk factors efficiently, focusing on the ease of completion with proper technique. Augmented feedback in reference to correcting landing strategies takes a minimal amount of time, is easily applied clinically.

There is a minimal amount of literature on motor learning in the pediatric population, however it is known that children have different information-processing abilities than adults, such as selective attention and speed of information processing (Sullivan et al. 2008).

Sullivan et al. (2008) found that children who receive feedback after every trial of a motor task (100% feedback) had greater retention than children who received reduced feedback, and in fact performed comparably to adults at the end of acquisition and retention trials. A

combination of verbal and visual augmented feedback may be the best way for pediatric athletes to comprehend and execute biomechanical intervention strategies in an on-field setting. By stimulating multiple senses it will be easier to maintain the attention of athletes performing the intervention and to ensure proper form, and verbal instruction will provide feedback and confirmation of proper technique.

The purpose of this study was to determine if one session of augmented feedback given to pediatric soccer players after performing a jump landing task would alter, peak vertical ground reaction force (VGRF), peak anterior tibial shear force (ATSF), knee flexion angle at initial contact, peak knee flexion, peak knee extension moment, knee valgus at initial contact, peak knee valgus, and peak knee valgus moment. A secondary objective for this study was to determine if augmented feedback has a greater effect on landing mechanics than practice alone in subjects that do not receive feedback. We hypothesized that subjects who received augmented feedback would alter these variables in order to reduce risk of ACL injury.

METHODS

Subjects

Twenty seven female subjects were recruited from an area soccer league's Under-11 age division (age = 10 ± 1 years, height = 141.02 ± 6.72 cm, weight = 33.55 ± 5.28 kg). Subjects were randomly assigned groups by choosing a number from a hat without replacement. Group one (CON) was the control group, and did not receive any feedback. Group two (FB) was the intervention group, and was provided with feedback.

Inclusion / Exclusion Criteria

Subjects were eligible to participate in the study if they were on the official roster for the Under-11 age division, and engaged in soccer activity for 1 hour at least 3 days per week. Any of the subjects that had an injury that prohibited them from soccer participation at the time of testing were excluded. Subjects were also excluded if they had a history of lower extremity injury that required surgical intervention within the past year, or were completing a formal rehabilitation program at a physical therapy clinic.

Measurement & Instrumentation

All measurements were conducted on the dominant leg of each subject, which was defined as the leg used to kick a ball for maximal distance (Hanson et al. 2008). A 7 camera infrared optical motion capture system (Vicon Motion Systems, Centennial, CO) was used to sample knee kinematics during the task by capturing the movement of reflective markers attached to each subject at a frequency of 120 Hz. Landing forces were sampled from a force plate (Bertec Corporation, Columbus, Model 4060) at a frequency of 1,200 Hz, and were combined with knee kinematics via an inverse dynamics procedure to derive knee kinetics. All data were collected using Vicon Nexus Software (Vicon Motion Systems, Centennial, CO).

Procedures

Subjects reported to the a biomechanics laboratory for a single testing session lasting approximately one hour. Informed consent and assent forms approved by the Institutional Review Board were completed prior to the testing date. Upon arriving at the laboratory, the subjects completed a questionnaire to screen for current injuries that prohibited them from

playing soccer, and their height and weight were recorded. The subjects were then randomly assigned to groups without replacement.

Subjects donned spandex short and shirt and wore their own sneakers.

Retroreflective markers were placed on the subjects bilaterally on the acromion processes, greater trochanters, anterior inferior iliac spines, anterior thighs, lateral femoral condyles, medial femoral condyles medial malleoli, tibias, lateral malleoli, and sacrum. Markers were also placed on the subjects' shoes, representing the head of the 1st metatarsal, head of the 5th metatarsal, and calcaneus.

Following marker placement, the subjects were asked to stand in the center of the calibration area (2.5 m × 2.5 m × 1.5 m) to collect a static calibration trial. Following the static calibration trial the retroreflective markers on the medial malleolus and medial epicondyle were removed for ease of movement during data collection of the jump landing task.

Both groups performed the same jump landing task from a 30 cm box that was placed at 50% of the subjects' height from the edge of the force plate. The jump landing task has been used consistently in literature to obtain information on kinetics and kinematics at the knee in order to determine potential risk factors for ACL injuries (Fagenbaum and Darling 2003; Pflum et al. 2004; Barber-Westin et al. 2005; Hass et al. 2005; Hewett et al. 2005; Myer et al. 2007). Subjects were instructed to jump forward and land with their feet on the force plates, and then immediately jump up for maximum vertical height upon landing. Trials that were not performed correctly were eliminated and repeated. A bad trial was defined as subjects not landing with their entire dominant foot on the force plate, jumping vertically instead of jumping horizontally toward the force plate, or if the non-dominant foot

landed on the force plate being analyzed. Subjects performed 3 trials of the jump landing task prior to and immediately following an intervention period.

Control Group

After the initial jump landing task the subjects in the CON given one minute of rest. They then performed the second jump landing task and were given one minute of rest between each trial in order to emulate the time needed to provide feedback to the FB group.

Feedback Group

The FB groups also performed a jump landing task were then provided with feedback lasting approximately one minute. The scripted feedback consisted of: “I want you to remember three things. 1) Bend your knees when you land. 2) Land softly so you can barely hear your feet hit the floor, and 3) Land with your knees in a straight line over your toes.” Visual feedback was also provided by the researcher in order to emphasize the body motions within the scripted feedback. The subjects then performed another jump landing task, and received feedback between each trial, which is at a rate of 100% (Janelle et al. 2003; Emanuel et al. 2008; Sullivan et al. 2008).

Data Reduction

World axes were defined, where x was positive in the anterior direction that the subjects were facing, y was positive to the left of each subject, and z was positive in the superior direction. Phases of the jump landing task were defined by the vertical ground reaction force. Initial ground contact was defined as the point at which the vertical ground reaction force exceeded 10N. Take-off was defined as the point after initial ground contact at which the vertical ground reaction force dropped below 10N. All data were analyzed within the time interval from initial contact until take-off, defined as the stance phase. All peak

angles, forces, and moments were measured during the stance phase. Data reduction was performed using Motion Monitor software and a customized software program (MatLab). Force measurements were normalized to body weight, and moments were normalized to the product of body weight and height.

Data Analysis

All data were analyzed using SPSS 15.0 (SPSS, Inc. Chicago, IL). An alpha level of 0.05 was set and a power analysis was run post data analysis. A 2x2 (group x time) Mixed Model ANOVA was conducted to answer the research questions. A Tukey post hoc analysis was conducted on data that were determined to be statistically significant, and effect sizes were calculated for all data.

RESULTS

Three trials and one subject were not analyzed as the vertical ground reaction force data were corrupt due to large amounts of missing forceplate data within the trial, and subsequently accurate kinetics and kinematics were unable to be obtained. Three displayed large amounts missing forceplate data in vertical ground reaction forces for one trial, while one subject was also affected by corrupt vertical ground reaction force data in all trials, and was therefore removed completely from analysis, resulting in 13 subjects per group.

Means and standard deviations for kinematics and kinetics data are presented in Tables 3 and 4, respectively. Statistical analyses revealed significant group by test interactions for anterior tibial shear force ($F_{1,24}=4.32$, $p=0.05$) and vertical ground reaction force ($F_{1,24}=8.497$, $p=0.01$). Tukey post hoc analysis of anterior tibial shear force data (MSD critical value = 0.10 N/Kg) revealed a significant difference between CON and FB groups post intervention (mean difference = 0.19 N/Kg) suggesting that the decreased anterior tibial

shear force in the feedback group was due to the augmented feedback. Tukey post hoc analysis of vertical ground reaction force data (MSD critical value = 0.63 N/Kg) revealed significant differences within the feedback group from pre to post intervention (mean difference = 0.99 N/Kg) and between control and feedback groups post intervention (mean difference = 0.91 N/Kg). There were no significant differences found between the groups at pre test, nor were there any differences observed within the control group between testing points. This suggests that augmented feedback reduced vertical ground reaction forces in the feedback group that was greater than the practice effect experienced by the control group.

Additionally, no significant group by test interactions were revealed for peak knee valgus moment ($F_{1,24}=1.63$, $p=0.21$) or knee extension moment ($F_{1,24}=0.86$, $p=0.36$). However, there was a large effect ($ES = 0.77$) (Table 4) associated with the feedback group's knee valgus moment data. This indicates that while not statistically significant the intervention may have had a clinically meaningful influence on knee valgus moment.

No significant group by test interactions were observed for the kinematic variables of knee flexion at initial contact ($F_{1,24}=0.07$, $p=0.80$), peak knee flexion ($F_{1,24}=1.16$, $p=0.29$), knee valgus at initial contact ($F_{1,24}=2.77$, $p=0.11$), and peak knee valgus ($F_{1,24}=2.63$, $p=0.12$). Based on these findings we conclude that these variables were not affected by the intervention. It should be noted that a moderate to large effect size was associated with the peak knee flexion angle data for the feedback group ($ES = 0.68$) (Table 3).

DISCUSSION

The purpose of this study was to evaluate the effects of augmented feedback on the landing mechanics of female pediatric soccer players. The primary findings suggest that subjects who received augmented feedback after each trial of a jump landing task over the

course of one testing session demonstrated significant decreases in ATSF and VGRF compared to a control group that did not receive feedback. Our findings support the hypotheses that augmented feedback would decrease anterior tibial shear force and vertical ground reaction force, however they reject the hypotheses that augmented feedback would decrease peak knee valgus, knee valgus at initial contact, knee valgus moment, peak knee extension moment, and would increase peak knee flexion and knee flexion at initial contact.

Our findings support previous research on decreasing VGRF with augmented feedback (Prapavessis and McNair 1999; McNair et al. 2000; Onate et al. 2001; Cronin et al. 2008). There were a lack of statistically significant results in our kinematic variables which may indicate that the necessary compensations involved in decreasing VGRF and ATSF may be occurring at a lower extremity joint other than the knee, such as the hip or ankle. Current literature suggests that a decrease in ATSF is a result of a change in sagittal plane kinematics (Sell et al. 2007). We chose to examine kinetics and kinematics at the knee as they have been shown to have an association with ACL injury in adults (Arms et al. 1984; Arendt et al. 1999; Bonci 1999; Ireland 1999; Hewett et al. 2005). In accordance with research on potential risk factors for ACL injury, the changes that we observed in VGRF and ATSF have profound clinical applications in that a decrease in these variables as a result of augmented feedback may lead to a decreased risk of ACL injury (McNair and Marshall 1994; Hewett et al. 2005).

Our findings support previous research which suggests that VGRF can be reduced with augmented feedback in adult populations (Onate et al. 2001). Studies on the effects of augmented feedback found that peak VGRF was significantly decreased in adolescents and adults, with adolescents decreasing VGRF by 19% after being given technical instruction

related to joint positions and auditory cuing (Prapavessis and McNair 1999; McNair et al. 2000). Prapavessis et al. (2003) researched the ability of nine year old children to decrease VGRF through the use of augmented feedback and found that the subjects in the instruction group significantly decreased VGRF in one session when compared to a control group, however they were unable to retain the information when tested again after three months. Our study found that pediatric females were able to decrease their VGRF by approximately an entire body weight when compared to a control group that remained virtually the same. This finding suggests that pediatric female soccer players may decrease their risk of ACL injury, when provided with simple instruction regarding proper landing mechanics.

A decrease in VGRF is clinically meaningful because peak ACL strain occurs at the instant of peak VGRF, indicating that a hard landing may be a risk factor for sustaining non-contact ACL injuries (Yu and Garrett 2007). Peak VGRF occurs simultaneously with peak posterior ground reaction force during stop jump tasks, which causes an external flexion moment relative to the knee. In response to this, an internal knee extension moment must occur through forceful contraction of the quadriceps, which in turn causes an increase in proximal ATSF (Yu et al. 2006). This supports the correlation that McNair and Marshall observed between anterior tibial acceleration and VGRF during a jump landing task (McNair and Marshall 1994). By decreasing VGRF as children, female soccer athletes may also be able to counteract the factors associated with increased risk that arises with changes in body structure in postpubescent females.

A study on the mechanism of non-contact ACL injuries revealed that ATSF is the primary component in anterior tibial translation and as a result places strain on the ACL during dynamic movements, which is the direct cause of ACL tears (Chappell et al. 2002; Yu

and Garrett 2007). Many biomechanical factors have been identified as possible predictors of ACL injury as they lead to increased ATSF and subsequent loading of the ACL (Arendt et al. 1999; Ireland 1999; Chappell et al. 2002; Yu and Garrett 2007; Shimokochi and Shultz 2008). Due to the relationship that has been found in previous studies between ATSF and ACL strain, the decrease we found in ATSF with augmented feedback can be applied clinically to potentially decrease the risk of ACL injury. The few studies that have been conducted on the effects of augmented feedback as an injury prevention strategy have not analyzed ATSF as a dependent variable. This is the only study thus far that has examined the pediatric population and analyzed additional kinematic variables as well as kinetics that have been identified as possible predictors for ACL injury. In examining the combination of kinematic and kinetic variables, the use of augmented feedback shows promise in decreasing the risk of ACL injury in pediatric females that participate in high risk sports such as soccer. The majority of current literature on augmented feedback as it relates to injury prevention focuses on adult populations (Prapavessis and McNair 1999; McNair et al. 2000; Onate et al. 2001; Cronin et al. 2008). Augmented feedback provides specific supplemental information about performance to the subject that they would otherwise be unable to obtain on their own through practice and sensory feedback (Onate et al. 2001). In pediatric populations preventative strategies that require lengthy attention spans and focused participation may not be easily applicable, and therefore may not serve as an effective injury prevention technique.

Our study is unique in that it evaluates the effects of augmented feedback on the landing mechanics of the pediatric population. It is important to take into account the motor learning abilities of children when incorporating augmented feedback into an injury prevention program. A study on skill acquisition in pediatrics found that children require

longer periods of practice with a greater frequency of feedback than young adults in order to optimize motor learning (Sullivan et al. 2008). The feedback given to the subjects in our study were concise and required a minimal amount of time, which allowed us to provide feedback after every trial (at 100% rate), and therefore the subjects were able to complete several jump landing trials while incorporating the feedback that was given to them, thus creating successful results. Our results suggest that female soccer players between the ages of nine and eleven are able to significantly decrease the amount of force sustained by their knees by providing them with simple instruction, and thus may be able to address biomechanical deficits before the onset of puberty, where risk of ACL injury increases in females when compared to their male counterparts.

Our study agrees with a that conducted by Prapavessis (2003) on the ability of children to decrease VGRF through the use of augmented feedback. It was found that the subjects in the feedback group significantly decreased VGRF in four sessions within one week when compared to a control group. In that study, however, the feedback group was not significantly different from the control group when tested at three months post initial instruction (Prapavessis et al. 2003). This indicates that pediatrics may not be able to retain the information provided in the feedback over long periods of time. As the subjects in this study were only provided with feedback during one session, trends in kinematic results may indicate the need to incorporate multiple sessions of augmented feedback over a greater length of time, such as in part of an injury prevention program, in order to see statistically significant results. In our study we did not evaluation the ability of the subjects to retain the feedback provided, so we are currently unable to compare that aspect to the study completed by Prapavessis (2003).

Based solely on the statistically significant differences that we found in VGRF and ATSF, our study has clinical significance as we have shown that simple augmented feedback can decrease those variables in nine to eleven year old female soccer players. By using this simple technique at the pediatric level it may be possible to address biomechanical issues in female athletes before they become poor habits, and it may therefore be possible to reduce the risk of ACL injury in that population as a direct result of decreasing ATSF.

Although not all of the measured variables revealed statistically significant differences, comparisons within the feedback group suggested that there were trends from pre to post intervention that with additional subjects may have elicited statistically significant differences. These trends were suggested by our findings of moderate to large effect sizes of peak knee flexion and knee valgus moment. The changes observed for peak knee flexion and knee valgus moment show promise clinically in decreasing the risk of ACL injury as the feedback group displayed a 70% decrease in knee valgus moment, and peak knee flexion increased by approximately 7°, which represents a 9% increase. This is important in decreasing risk of ACL injury as greater knee flexion and lesser knee valgus moment cause a decrease in ATSF, and in turn decrease the load sustained by the ACL (Yu and Garrett 2007).

There are many directions in which future research on this subject may lead to new discoveries regarding ACL injury prevention beginning in the pediatric population. Similar studies may be conducted to determine the effects of augmented feedback on different age groups in the pediatric population, as well as observing if pediatric males and females respond differently to augmented feedback. Future studies may also examine the effects of multiple sessions of augmented feedback over time on kinetic and kinematic variables, which may also extend into researching multiple lower extremity joints to determine where

modifications have occurred in order to cause a decrease in VGRF and ATSF. When analyzing the effects of augmented feedback on landing mechanics a study on the retention of initial feedback provided should be examined. Researchers may also find it prudent to determine if augmented feedback given over a substantial period of time will decrease the incidence of ACL injury in pediatrics.

We acknowledge that the current study has several limitations, one of which is the sample size. The conclusions drawn from this study can only be applicable to females between the ages of nine and eleven. In accordance with this, no analysis was completed on the subjects' psychological abilities to retain and incorporate the feedback provided. As with many laboratory studies, the jump-landing task was performed with retroreflective markers attached to the subject, and while the jump-landing task is an athletic movement, it may not be a true indication of movement on an athletic field. Also, this study cannot actually determine if decreasing any of the measured variables will actually result in a decreased risk of ACL injury as we have not followed our subjects over time.

The current study investigated the effects of augmented feedback on kinetic and kinematic variables associated with pediatric landing strategies during a jump-landing task. Based on the results of this study it can be concluded that:

1. Augmented feedback significantly decreases ATSF and VGRF in female pediatric soccer players, and may reduce the risk of ACL injury.
2. While kinematic variables did not yield statistically significant results, further investigation is needed to determine if the necessary compensations for decreasing VGRF and ATSF are coming from a joint other than the knee.

3. Moderate to large effect sizes observed in knee valgus moment and peak knee flexion warrant further investigation to determine if augmented feedback may elicit significant differences with a greater number of subjects.

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